Spatial Variations of the Wave, Stress and Wind Fields in the Shoaling Zone

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LONG-TERM GOAL

Our long term goals are to improve parameterization of surface fluxes in the coastal zone in the presence of wave growth, shoaling, and internal boundary layer development. These goals include improving the present form of similarity theory used by models to predict surface fluxes and stress over water surfaces and documenting development of internal boundary layers in the coastal zone that are currently not modelled correctly, particularly in cases of flow of warm air over colder water.

OBJECTIVES

Our objectives are to provide quality controlled data sets which include spatial variation of surface fluxes, stress and wave characteristics and provide vertical structure of the wind and thermodynamic variables in the coastal zone. The objectives also include both evaluation of present formulations for surface fluxes at the air-sea interface and evaluation of model simulations of internal boundary layer development.

APPROACH

The first approach has been implementation of an extensive literature survey on existing studies of air-sea interaction in the coastal zone and internal boundary layer development. The second approach is implementation of three field programs, one completed in fall of 1997, one completed in spring of 1999 and one in fall of 1999. The spring 1999 field program was designed to study the internal boundary layer in offshore flow, particularly in stable conditions. The third approach is data analysis and evaluation of existing boundary layer and surface flux formulations. The fourth approach is model comparisons with other groups.

WORK COMPLETED

The LongEZ fast response data from SHOWEX November 1999 has undergone a number of revisions and we have redone the quality control analysis after several of the revisions. We believe that this task is now completed, pending any additional data difficulties revealed by the data analysis.

We are conducting an analysis of flux errors due to vertical displacement of buoys and aircraft and applying this analysis to the LongEZ and one of the flux buoys to-be-determined. We are concerned

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that such errors might be important in very stable conditions. We have also conducted an analysis of cospectra and possible flux loss in very stable conditions.

We have constructed several case study analyses of offshore flow using primarily the LongEZ data. In addition, we have constructed the horizontal variation of the fluxes, drag coefficient, roughness length and Charnock coefficient for all flight days.

I hosted a workshop on the SHOWEX field program in Corvallis on 6-7 Sept.

RESULTS

For stable flow of warm air over cool water, the sea surface momentum flux and turbulence (Figure 1) decrease rapidly with increasing fetch for the first few kilometers off-shore (to the right of the 5 km mark) and reaches very small equilibrium values. The land surface is revealed by the warm surface temperature and separates the cool Atlantic water from the cool inland water (far left of figure). The left side of the figure shows the near-collapsed turbulence over the inland water. The aircraft encounters the land internal boundary layer 1-2 km downwind from the inland coast.

The observed decrease in the sea surface momentum flux with travel time from the coast is predicted using a characteristic time scale of the turbulence in the upstream boundary layer over land. This suggests that close to the coast, advection and decay of residual turbulence strongly influence the air-sea momentum exchange. In this case, similarity theory is not adequate to predict the flux due to dependence on upstream conditions.

With flow of stable warm air over cool water, the residual turbulence advected from land becomes partially detached from the sea surface leading to a momentum flux and turbulence energy maxima aloft. Contrary to the usual concept of a boundary layer, the downward momentum flux increases with height. This is due to a combination of stronger dissipation of the advected turbulence at lower levels and less travel time available for decay at higher levels due to the increase in the mean wind with height.

With flow of unstable cool air over warm water, advection and decay of residual turbulence also occur. However, the relative contribution to the total turbulence level is less due to buoyancy generation of turbulence over the ocean. Unlike the stable case, the sea surface momentum flux for unstable flows is relatively invariant with fetch or travel time. In the unstable case, the momentum flux decreases with height as in traditional boundary layers.

Estimates of the individual terms in the equation of motion for the off-shore mean wind show that horizontal advection is the largest term. The vertical advection term, the vertical flux divergence term and the horizontal pressure gradient term all act to balance horizontal advection. Acceleration (deceleration) of the mean flow in the first few kilometers off-shore is associated with an increase (decrease) in the downward momentum flux with height and mean sinking (rising) motion.

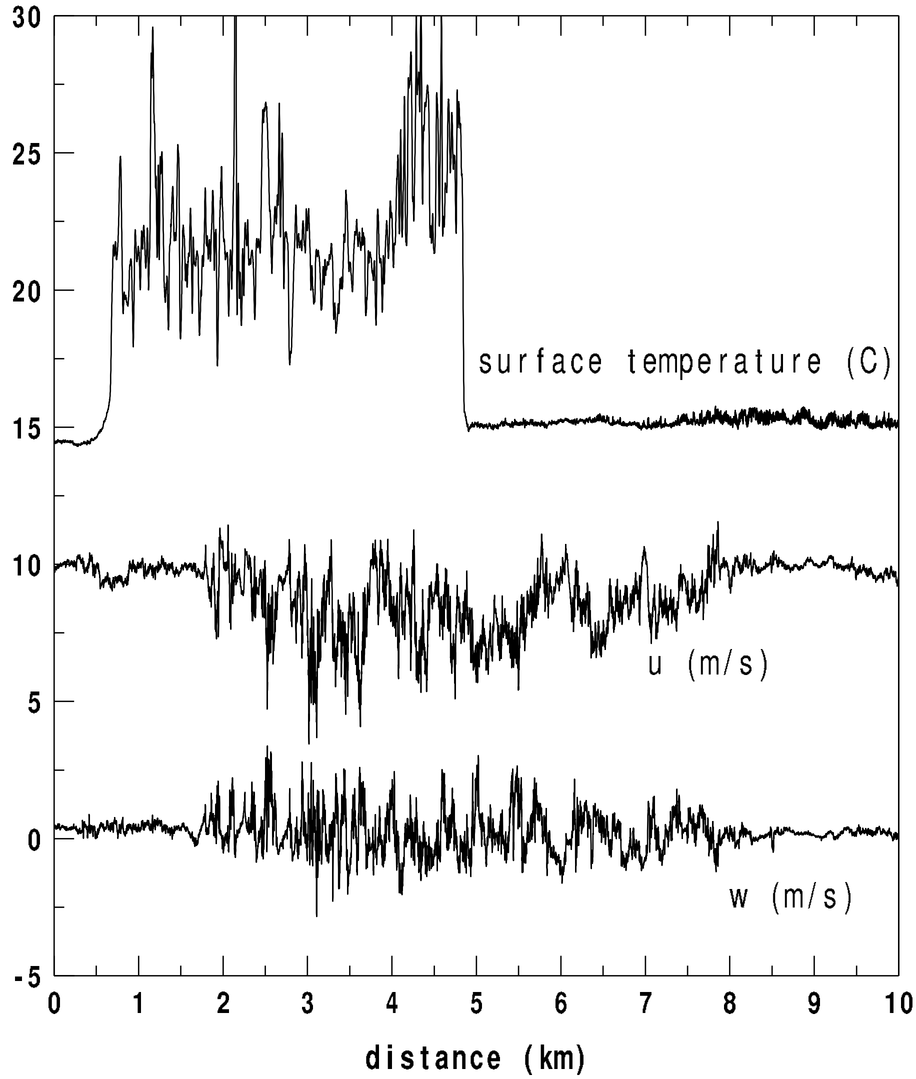

Figure 1. Surface radiative temperature, horizontal wind speed and vertical wind speed as a function of distance km for one aircraft flux leg at 110-m altitude on 14 Nov 1999 as the aircraft travels West to East from over Albemarle Sound (left edge), over the Outer Banks (the warm region) and then over the Atlantic Ocean. The mean flow direction is westerly.

For cases of offshore flow of warm air over cold water, the turbulence may essentially collapse due to the small roughness length of the water and due to the stable stratification. This quasi-frictional decoupling is due to a feedback between the reduced downward flux of momentum, which leads to reduced surface roughness, which in turn leads to less turbulence and downward mixing of momentum. The recovery of the atmospheric boundary layer occurs only after the wind accelerates (due to frictional decoupling) and the air-sea temperature differences decreases (due to cooling of the atmosphere). This may occur after 10-20 km or may require up to 100 km of fetch. In the later case, the very stable semi-collapsed state was terminated by flow over the warm gulf stream.

The analysis of the Charnock coefficient is more complex. In the semi-collapsed cases, the Charnock coefficient is generally much smaller than usual values assigned to this coefficient. However in some cases of downward transport of turbulence kinetic toward the surface, the Charnock coefficient is very

large. These cases correspond to generation of turbulence above the surface which then mixes downward toward the surface. Very large values of the Charnock are also observed for some neutral conditions. We need to investigate the role of wave state using the Ku band radar and scatterometer as well as observations from the Twin Otter. The influence of possible flux loss for very stable conditions and the possibility that the LongEZ flies too high above the surface (15 m) for very stable conditions is being investigated.

IMPACT/APPLICATION

Clearly the Charnock formulation leads to large errors in formulation of the stress in the coastal zone. Atmospheric stability, wave state and advection of turbulence from land, all exert a strong influence on this formulation. The ability of existing platforms to measure fluxes in very stable conditions of offshore flow of warm air over cold water is being questioned, although it is not yet know if the errors are fatal.

RELATED PROJECTS

Analysis of offshore tower eddy correlation data from two Scandanavian sites is being carried out under grant N00014-98-0282 from the Office of Naval Research. This data allows analysis of detailed vertical structure in the lowest 40 m whereas the above work concentrates on horizontal structure in the coastal zone.

PUBLICATIONS

Vickers, Dean, L. Mahrt, J. Sun and T. Crawford, 2000: Structure of offshore flow. To appear in *Monthly Weather Review.*

Sun, J., D. Vandemark, L. Mahrt, D. Vickers, T. Crawford and C. Vogel, 2000: Momentum transfer over the coastal zone. Submitted to *J. Geophys. Res.*